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Long-action of additional horizontal prestressing on masonry

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Abstract

This article is focused on verifying behaviour of a brick masonry which was horizontally post-tensioned. An experimental model of three walls has been built for the measurement. The model is in scale 1:1 and represents a part of a real structure. Longitudinal strain of brick walls has been measured by wire strain gauges in important places. Surrounding temperature and temperature inside the walls were also recorded. Results of the experiment have been continuously evaluated and compared with the simplified numerical models. Right now we have a better picture of actual behaviour of the brick masonry wall which was horizontally prestressed and we are able to design appropriate restoration works for historical buildings.

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*Keywords:*masonry; addition prestressing; strain; brick walls; experimental measurement

1. Introduction

The existing historic buildings are strengthened by different methods. One of those methods is strengthening with additional prestressing. This way of restoration was used on different construction types – family homes, castles, towers, churches, but also in civil engineering (for ex. masonry arch bridges) [1], [2], [3]. The restoration works done so far convincingly show that strengthening with prestressing is effective and above all, gentle. There are minimal alterations made to existing structures – mounting ropes, anchor plates, steel deviators and boring or milling

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spare cable channels. The biggest advantage is that after finishing work, the alterations made to the load-bearing structure are not visible. The preservation of the original architectural appearance after the strengthening is especially wanted with protected heritage objects.

When strengthening with additional prestressing, there is a need for good proposal, which will adhere to the process and technology of prestressing. There are several things that must be determined; size of prestressing and the appropriate order and arrangement of prestressing cables. While creating the proposal, it is also important to determine the material characteristics of the existing object, which can be hard with masonry objects. Structural behaviour is determined by the composite material (bricks and mortar) in interaction with the foundation and subsoil. It's especially difficult to determine the solidness of the masonry, which is being strained by prestressing parallel to bed joint.

This article is focused on the experimental examination of long-term behaviour of the structure part, which was additionally strengthened by horizontal prestressing. The intention of this measurement isn't only the observation of unit deformation at designated places, but also future comparison of the evaluated results with more complicated numerical models – detailed micro models.

2. Experimental model description

An experimental model of three brick walls was built in the university area, for measurement. It represents a part of the real horizontally post-tensioned structure, in 1:1 scale. It's the segment of the St. Michael Archangel church in Švábenice (Fig. 1), which was built in baroque style during 1716-1718. The church is built on a slope and already had some issues with the stability of gable and tower during the 18th century. Definitive stabilisation has been achieved thanks to a huge reconstruction in 1997, when the church was braced lengthwise with prestressing.

A new reinforced concrete strip was built on the perimeter of the church at a depth of 1,2 m under terrain, which was encircling the chancel and nave of the church. The strip was prestressed with monostrands. A concrete-steel threshold was built in front of the tower foundation and at the same level like the above mentioned strip. The threshold was also prestressed with monostrands, so the circle of prestressed foundations was closed up. Subsequently, the monostrands placed in the grooves created peripheral (spatial) enlacement of the object close above and under the church windows. The obvious cracks in the structure have been injected beforehand, so that there was no unwanted closing of existing cracks during the prestressing, which could do even more damage to the structure.

a) b)

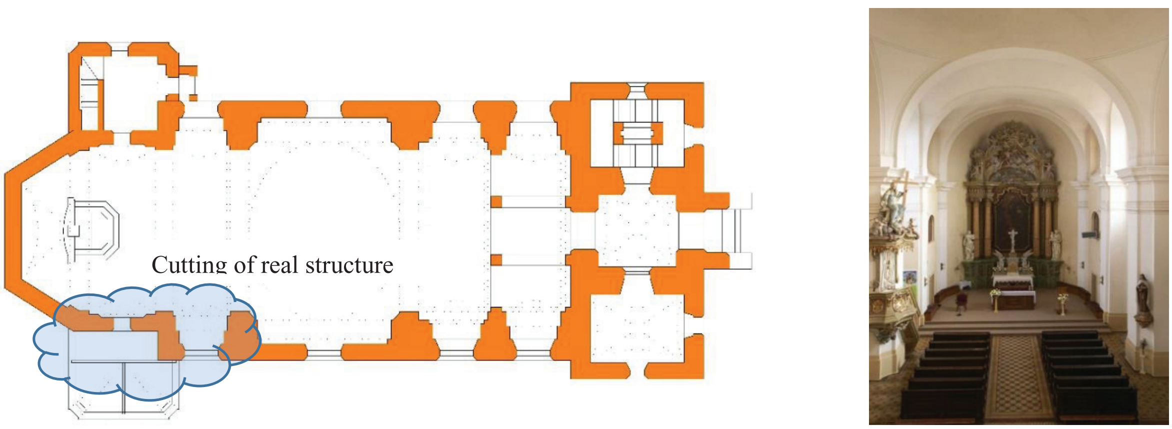


Fig. 1. (a) Ground plan of church; (b) View of reconstructed church

The experimental walls in the university area were built on new concrete-steel strips with openings that allow vertical prestressing. Asphalt strips in two layers were smelted between the strip footing and new masonry. The experimental walls were built from fittings of full fired bricks CPP 290x140x65mm P15, which were connected with M5 type MVC cement-lime mortar.

The vertical prestressing of cables, which replace the gravitational weight on real structures, was done in the first phase at 31st October 2011. The number of prestressing ropes and the stretching force was calculated, so that the tension from the contribution of the vertical prestressed cables would rise to 0,466 MPa in the measured wall. The numbering of the cables is shown in Figure 2. The time flow of prestressing individual cables and the stretching force are recorded in the following table (Table 1). Before anchoring, the stretching force was suspended for 3 minutes, after which time the tension rose to required strength.

Table 1. Vertical prestressing

Indication of cable	Tension force [*kN*]	Time [hours]
1	210	9:45 – 9:51
2a; 2b	158	10:07 – 10:12; 10:15 – 10:17
3a;, 3b	210	10:42 – 10:47; 10:50 – 10:56
4a; 4b	158	11:02 – 11.08; 11:12 – 11:17
5	210	11:22 – 11:28
6	210	12:01 – 12:08

a) b)

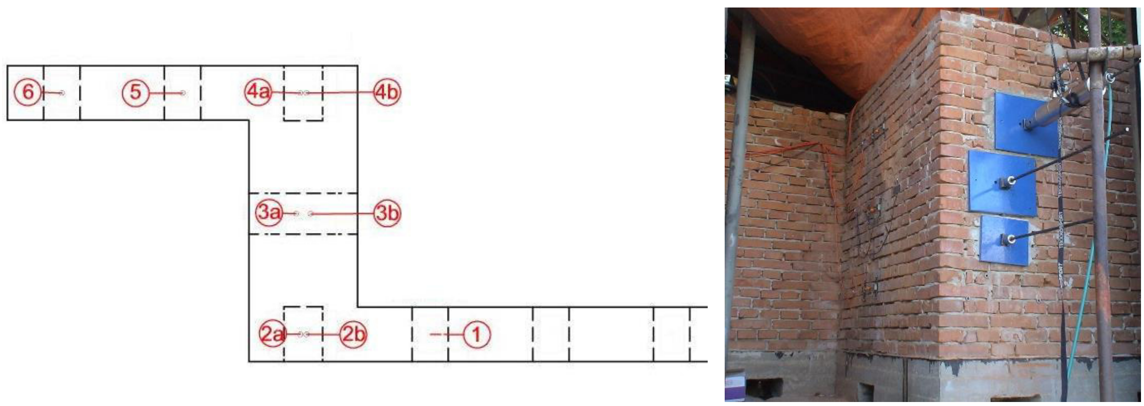


Fig. 2. (a) Plan of vertical prestressing; (b) View of measured model (three brick walls)

Horizontal prestressing parallel to masonry bed joint was introduced to the middle wall during the second phase, conducted on 2nd July 2012. Long term monitoring has been conducted ever since. Prestressing of the cables according Fig.3 proceeded as shown in table 2.

Table 2. Horizontal prestressing

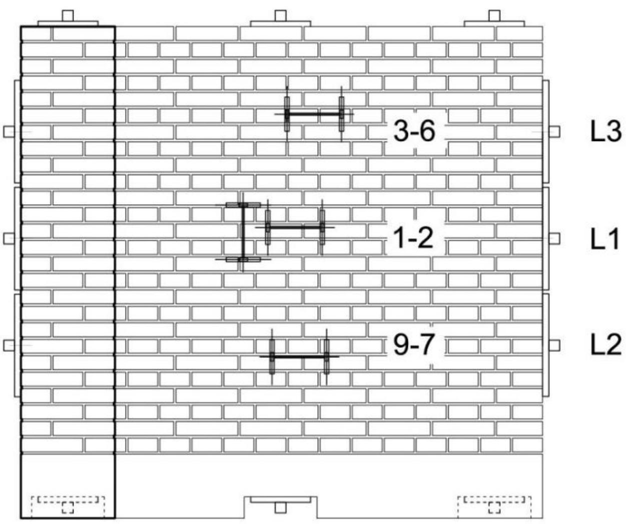
Tension force [*kN*]	Sequence of cables
40	1, 2, 3
80	3, 1, 2
120	2, 1, 3
160	3, 1, 2
180	2, 1, 3
200	3, 1, 2

3. Description of carried out measurements

Long term measurement of the wall is carried out with eight wire strain gauges recording unit deformations, and two resistance temperature detectors that measure the temperature at the surface and in the core of the wall. The wall deformation is measured in three height levels, always at both wall surfaces. Strain gauges 1 and 2 are attached to the middle part of the measured wall. Strain gauges 3 and 6 are placed at the top margin; strain gauges 7 and 9 are placed at the bottom part of the wall. The last two strain gauges number 4 and 5 are placed in the middle of the wall and they're measuring the wall deformation in vertical direction.

All strain gauges have an identical measuring base length of 255 mm (10 inch) and were attached to the brick wall using steel plates with epoxy resin. The sensors monitoring the temperature inside and on the surface of the wall were attached in order to find out how the masonry reacts to different temperatures on the surface and inside of the cross-sections (thermal inertia). Fig. 3 depicts the side view a) of the experimental wall with the position of strain gauges and their labels.

a)



b)

Fig. 3. (a) Labelling of strain gauges; (b) Wire strain gauges

Several unpleasant situations occurred during the long term measurement, when the measuring system failed. It was caused by low temperatures and bad weather conditions, when the central with strain gauges stopped working (low temperature and high humidity). Strain gauges number 6 and 7 also stopped working for unknown reasons (failure was discovered 6th November, 2012). To continue with the measurements, the strain gauges were checked and once again tuned to assessable frequencies.

4. Illustration of measured values

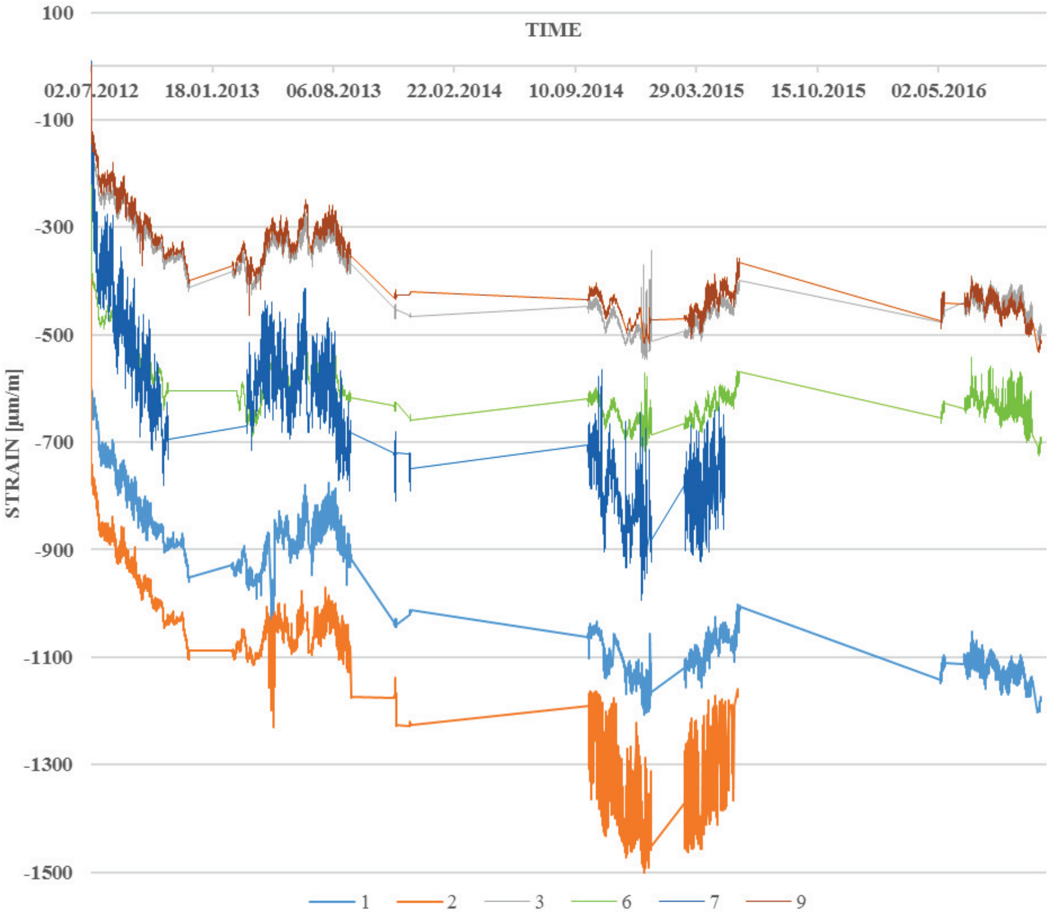


Fig. 4. Long-term monitoring of deformation [µm/m]. In the middle section is strain highest (gauges no. 1 and 2)

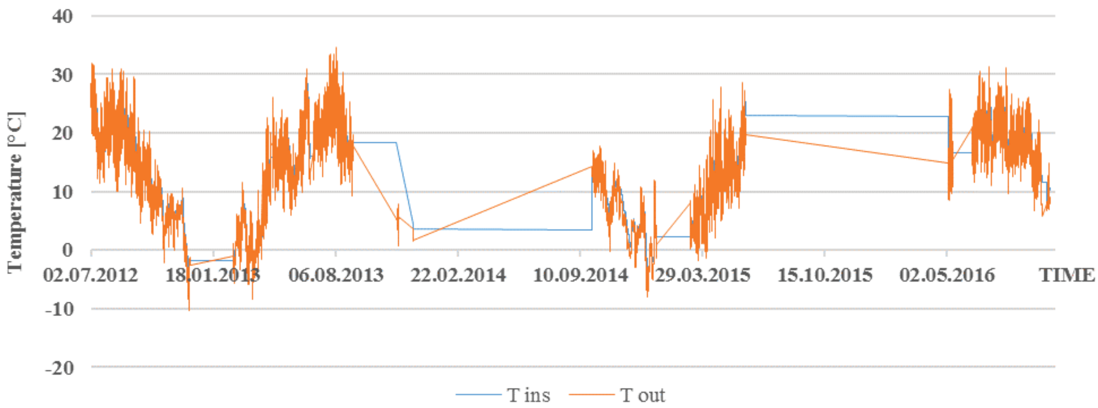


Fig. 5. Long-term monitoring of masonry surface and core temperature.

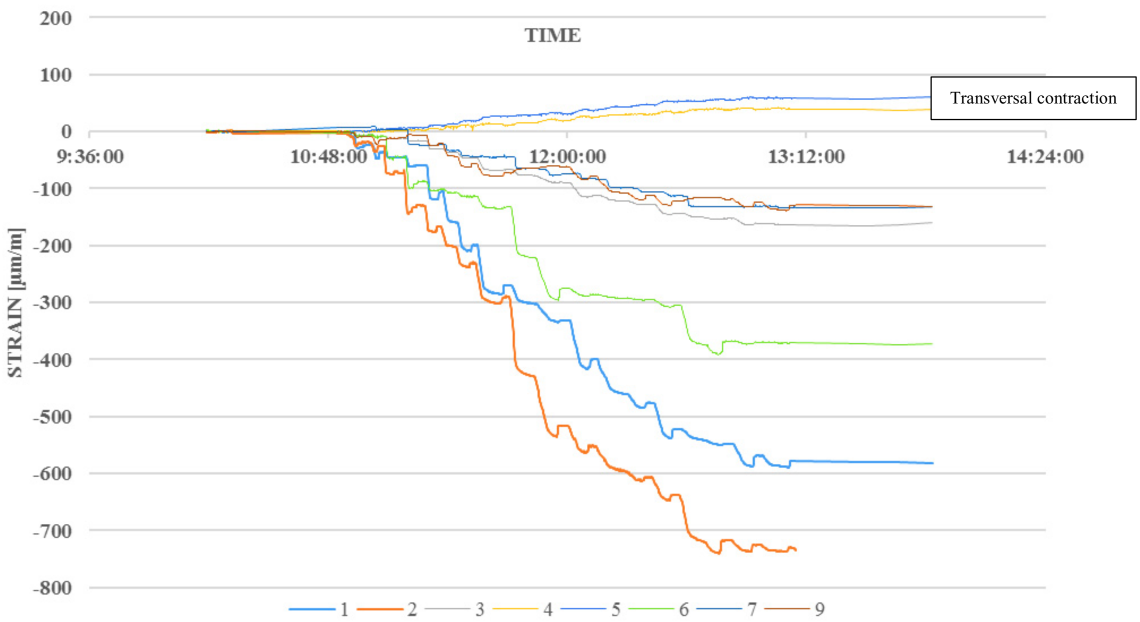


Fig. 6. Short-term monitoring of deformation during prestressing of horizontal cables. Gauges no. 4 and 5 have been shown transverse contraction

5. Conclusion

The experimental model is monitored long-term (Fig. 4) and the measured values are being continually evaluated. It's obvious from the already measured results that the masonry is yielding from the long-term prestressing also in the horizontal direction. The attempt to determine it can be used for estimating the long-term loss of prestressing, according to our knowledge no similar experiments have been published yet [4]. The 20 minutes' data reading frequency allows for reliable filtration of fluctuations in the measured values. The wire strain gauges also manifest high sensitivity to ambient temperatures, where the peaks of daily temperatures will show in the measured frequency of the wire strain gauges. Figure 5 shows that surrounding temperature is usually different than core of the wall.

Numeric models will be created to evaluate the results of the experimental measurement, which will be collated with measured data. The result should be an easier creation of a model. The influence of the two adjacent walls (solid construction units) that partially absorb the inserted prestressing should also be taken into account.

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